Web-based Medical Teaching using a Multi-Agent System

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Abstract

Web-based teaching via Intelligent Tutoring Systems (ITSs) is considered as one of the most successful enterprises in artificial intelligence. Indeed, there is a long list of ITSs that have been tested on humans and have proven to facilitate learning, among which we may find the well-tested and known tutors of algebra, geometry, and computer languages. These ITSs use a variety of computational paradigms, as production systems, Bayesian networks, schema-templates, theorem proving, and explanatory reasoning. The next generation of ITSs are expected to go one step further by adopting not only more intelligent interfaces but will focus on integration. This article will describe some particularities of a tutoring system that we are developing to simulate conversational dialogue in the area of Medicine, that enables the integration of highly heterogeneous sources of information into a coherent knowledge base, either from the tutor's point of view or the development of the discipline in itself, i.e. the system's content is created automatically by the physicians as their daily work goes on. This will encourage students to articulate lengthier answers that exhibit deep reasoning, rather than to deliver straight tips of shallow knowledge. The goal is to take advantage of the normal functioning of the health care units to build on the fly a knowledge base of cases and data for teaching and research purposes.

1. Introduction

Technologies as broadband networks, where hypermedia, virtual reality and artificial intelligence constitute the founding base of the so called e-learning world, are a quaint reality. Information and knowledge systems developed under the form of front-ends supported by Web technology have proliferated. In fact, small farms of e-learning sites in the Internet exist that integrate and distribute information worldwide, namely to physicians, patients or students, just to name a few. They have developed themselves in a way so ubiquitous that they are becoming victims of their own popularity.

Technological problems related to the maintenance of a high number of specific sites directing the stream of information, knowledge and services and serving several users have been well described in the literature [1]. To overcome these drawbacks, work is being done on the consolidation and integration methodologies of multiple small Web sites in an only entity: the so called e-learning holding portal (portal is a new internet word that started to catch up very strongly in the last few years. It refers usually to a main guide that includes a search engine, plus additional content, such as current news or entertainment info, designed to keep someone at the portal for as long as possible). Operational efficiency and cost reduction can be achieved using holding portals throughout information centralization, directing business or educational processes, and linking users for eventual collaboration, going from the e-business, e-procurement, e-health up to e-learning.

The vitality of a holding portal lies in its integration potential, in support of communities of virtual entities and in the gathering, organization and diffusion of information. Any good strategy for the creation of such a system should capitalize in this point. The departments, schools, or entities usually have different architectures, different people in charge, and duplicated information. Thus it would be desirable to join these different states into one (i.e. in terms of a holding).

1.1 Medical Teaching

Today more than ever, learning medicine is a huge challenge. It requires developing a vast range of manual, intellectual, visual and tactile skills as well as taking into account large amounts of factual information. As the result of medical research everyone is faced to a constant impact upon clinical practice. Continued medical education is essential. Traditionally, medical teaching is based on texts, lectures and bedside teaching, with self-guided individual learning from books being the most common. It is believed that traditional medical teaching and individual learning in particular, can be complemented with electronic systems delivered on the Internet/Intranet. Indeed, one of the advantages of electronic systems in teaching is that it opens the road to increase the learner's involvement. The learner can set the pace, choose the content and select the mode of presentation according to the requirement of his/her individual preferences and situations. Awareness of the knowledge constructing process is increased, as well as the satisfaction gained from learning. As an overall result, medical teaching can be more effective and efficient.

1.2 e-Learning

The electronic learning, which will be referred to as e-Learning, can be defined basically as the electronic systems in teaching/learning that are produced through

Web technology. Among its components are found distributed contents in multiple formats, learning experience administration, network community of apprentices, content developers and experts. Thus, the term e-Learning refers to the use of Internet technologies to provide an extensive spectrum of solutions that improve knowledge and performance in teaching/learning [2,3].

One of the main impacts of e-Learning in education resides in the fact that it provides opportunities to create resources that turn the learning process flexible. This implies a different relation between teachers and students and even between institutions, in the sense that the students participate on their own formation and the vertical hierarchy tends to become increasingly more horizontal.

1.3 Multi-agent systems

Multi-agent Systems (MAS) may de seen as a new methodology in distributed problem-solving via theorem proving, i.e. agent-based computing has been hailed as a significant break-through in distributed problem solving and/or a new revolution in software development and analysis [21-23]. Indeed, agents are the focus of intense interest on many sub-fields of Computer Science, being used in a wide variety of applications, ranging from small systems to large, open, complex and critical ones [4,5]. Agents are not only a very promising technology, but are emerging as a new way of thinking, a conceptual paradigm for analyzing problems and for designing systems, for dealing with complexity, distribution and interactivity. It may even be seen as a new form of computing and intelligence.

To develop such systems, a standard specification method is required, and it is believed that one of the keywords for its wide acceptance is simplicity [6]. Indeed, the use of intelligent agents to understand students and their knowledge, and to infer the most appropriate strategy of teaching from the interaction with the students offers the potential to set an appropriate software development and analysis practice and design methodology that do not distinguish between agent and human until implementation. Being pushed in this way the design process, the construction of such systems, in which humans and agents can be interchanged, is simplified, i.e. the modification and development in a constructive way, of multiagent based e-learning systems with a human-in-the-loop potential aptitude is becoming central in the process of agent-oriented software development and analysis [1,7].

This model has provided a clear means of monitoring the agent’s behaviour with significant impact in their process of knowledge acquisition and validation [8] and will be now applied in the development of intelligent agents that will support the e-learning system.

1.4 Intelligent Tutoring Agents

One of the present approaches in the field linked to electronic systems in medical teaching and Artificial Intelligence (AI), is the design of tutoring agents that supervise the user's actions in a data processing environment to provide aid. Specifically, tutoring agents are interface agents that cooperate with the users (e.g. students, health professionals) to reach an objective [9,10].

The idea is that computers may be employed to understand students and their state of knowledge, and to infer the most appropriate strategy of tutoring. Nevertheless, several factors delayed the development of the intelligent tutoring agents, namely the scarce knowledge that they have on cognition and human behaviour. These systems will improve following the progress on these areas (e.g. the problem of adapting the environment to the needs of the students [11]).

The complexity problem of intelligent tutoring agents design is due in part to the monolithic architecture in which it is based. An approach to the design of these systems, and others inside the AI field, tries to solve this problem applying a strategy of the type "divide and conquer", which give rise to the so called multi-agent systems or agencies [12]. These types of systems are formed by a series of agents that work like computational entities with complete autonomy and that communicate among themselves to carry out a concrete task.

To incorporate in this architecture a certain degree of user adaptability, enabling personalized learning, intelligent agents should be developed in such a way that each agent adapts itself in function of the system's necessities [13-16]. By **intelligent** we mean that the agent pursues its objectives and executes its tasks so that it optimizes some measure related to its good performance [8,17,18].

2. The Multi-agent System

In this section we describe our efforts and experience designing a MAS for e-learning in the medical arena. At the core of the designed system lays the data warehouse and a large amount of data (e.g. medical images, video, or text). This information is complemented with the knowledge base that defines its structure and classifies and defines the relationships between its parts. The upper level was developed in terms of a multi-agent system that accesses the information and presents it according to the meta-information and the specific task they are designed to do, which could be anything from pure textual referencing to a guided tour through a defined subject matter, to a three-dimensional annotated image reconstruction of an organ system (e.g. the students and health professional's interfaces). It was also developed a set of intermediate agents which will allow us updating and adding to the content database, authoring tools and medical data, and in doing so, will have to assure consistency within the meta-information (e.g., the medical data provider and the necessary teaching resources) (Figure 1). In terms of the internal representation of the information, suitable accepted formats, standards and protocols were used. At this early stage of the project, several options are kept open, but only when medical standards are not available. It was mandatory to have great flexibility in the automated database manipulation process, avoiding the risk of fixation on certain software and/or hardware vendors, enabling the system scaling as the project grows.

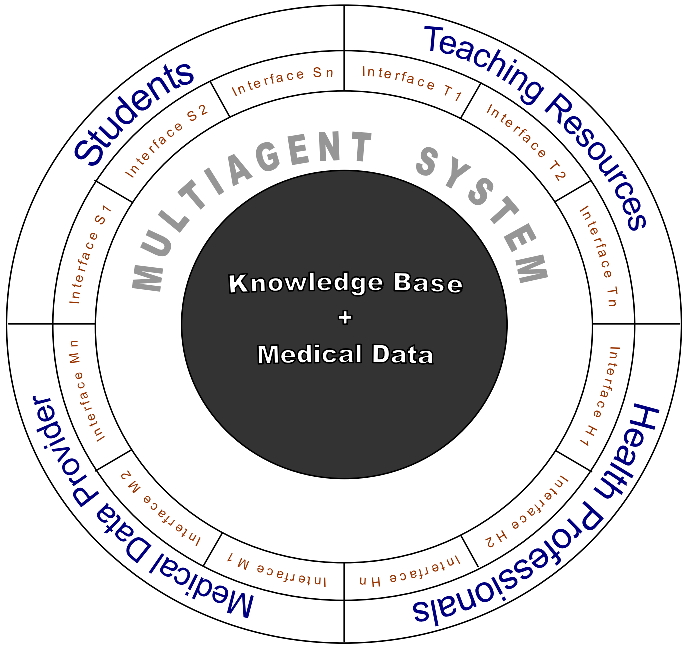

Figure 1 – Software structure layout

2.1 The Multi-Agent System architecture

We now report on the agents we developed, starting with a brief description of the basic type of agents and specifying the way they interact. To pursue this objective they were grouped into four complementary sets corresponding to the Medical Data Provider interfaces, the Health Professionals interfaces, the Teaching Resources interfaces and the Students interfaces (Figure 1).

The Medical Data Provider interfaces provide new medical data from medical equipment, mainly from medical imaging and from Electronic Medical Records (EMR).

The Health Professionals interfaces are used mainly by physicians that supply new medical information (e.g. image classification, case studies) to the system and use the existent information to help in their patient diagnostic task (e.g. look for a collection of cases similar to the patient he is studying).

The Teaching Resources interfaces supply new educational contents. Here they create and update case studies, exercises and contents for the e-learning process. They consult and link their teaching contents to the knowledge base and medical information stored by the system (with patient identity hidden). It should be pointed out that most of the teachers that use these interfaces are physicians in the Hospital that use the Health Professionals Interfaces for their clinical practices.

Students are the key elements of the system. They are registered in the system and their profile defined (choosing topics and interest areas). They search for study material, perform diagnostic testing through the case studies and answer to exercises and exams. They can also question the system. Simulators may also be provided.

The System is planned to perform some automatic tasks, such as evaluating the user's (Students, Teacher and Health Professionals) surf, generating the most suitable interface for them. This is done in terms of contents and not of interface design. We have tried out dynamic interface design but it was not very well accepted being quit confusing for the user.

2.2 Agent's Goals and Tasks

To implement the multi-agent system, six basic types of agents were defined. Table 1 presents the agents, their goals and their main tasks.

Table 1 – Agent's goals and tasks

Agents	Goals	Tasks	Interfaces
Profile Agents	Optimise the interface	Record user's preference Record user's tasks	Students Health Professionals
Evaluator Agents	Evaluate the user interface	Evaluate user's preferences and tasks Suggest interface improvements	
Information Producer Agents	Prepare information for the system (e.g., contents, medical images, case-studies, interfaces)	Add or change contents and systems functionality	
Research Agents	Find information with quality according to the user	Research information on Knowledge Base	Students Teaching Resources Health Professionals
Questions Agents	Reply to user questions	Try to get answers for students' questions. Question teaching resources about new topics Learn to deduct new answers	Students Teaching Resources
Anonymize Agents	Hide patient identification in data	Produce anonymized replica of medical information	Medical Data Provider Health Professionals

2.3 Agents Interaction

We have split the system in five parts. The first four are the main areas and the last one represents the system core.

2.3.1 Medical Data Provider Interfaces

The following scheme describes how Medical Data Provider Interfaces supply information to the system. When Medical Data Provider sends data to the Knowledge Base an Anonymize Agent replicates anonymous data that may be used by the Information Producer Agent to create new contents for educational proposes. The process of information production may involve joining other data that exists in the Knowledge Base. The two agents use a communication method to announce their state through the Black Board (a shared memory) (Figure 2).

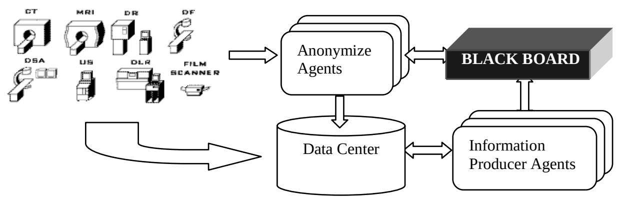

Figure 2 – Medical Data Provider

2.3.2 Health Professionals Interfaces

Health Professionals are other suppliers of information to the system. The system's response is similar to the Medical Data Provider Interfaces. They also need to retrieve information from the system in order to perform better diagnostics. Research Agents are responsible to make available the most suitable information for the health professional (Figure 3).

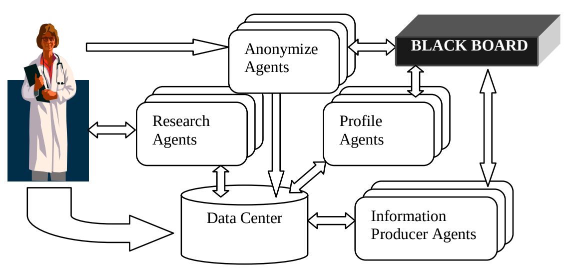

Figure 3 - Health Professional Interface

2.3.3 Teaching Resources Interfaces

Teaching Resources represent essentially teachers that can supply the system with new contents and answer questions made by the students. Teachers use a Research Agent to find relevant information and use them to produce new materials. The Profile Agent is responsible for starting the improvement of the available interface, learning preferences and analysing preferences of each user. The Questions Agent tries to get the best answer for unsolved questions (Figure 4).

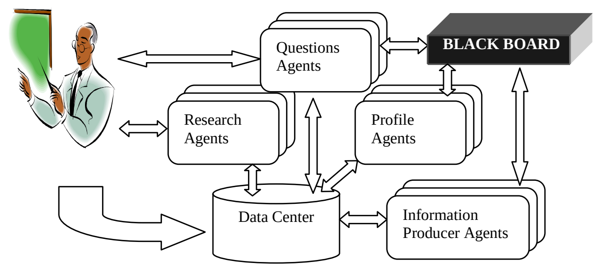

Figure 4 - Teaching Resources Interface

2.3.4 Students Interfaces

Students use Research Agents to get educational guides, contents, diagnostic tests, exams, etc. They may use Questions Agent to obtain answers and submit questions. Profile Agent can be used by the students to personalise the system, but it works all the time trying to deduct what will be the best system configuration for each individual (Figure 5).

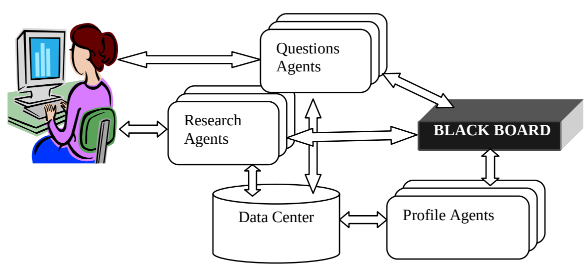

Figure 5 - Students Interface

2.3.5 System

The following scheme describes how the system runs in the background, trying to improve itself, searching for the friendliest interface, optimising the system. The Evaluator Agent permanently uses the records made by the Profile Agent. It suggests to the Information Producer Agent changes to the interface.

Establishing a partnership with the user is crucial for the success of the system, like in the traditional education where the students have quick answers for their challenges (Figure 6).

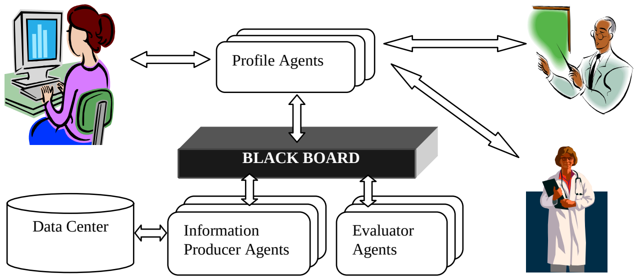

Figure 6 – Multi-agent profile adjustment

3. The Multi-agent System implementation

In order to achieve these benefits, electronic systems in medical teaching must meet well defined requirements. On the infrastructural side, client/server network architecture is required, where a Storage Area Network (SAN) holds the data warehouse, medical data (e.g. medical imaging) and most of the specific software agents that deliver medical content. This approach enables continuous content updates and assessment. The network should allow fast transfers with low latencies to avoid waiting times. Finally, the client computers where the learners work on should be easy to set up and economical. Fortunately, the new academic and Hospital networks currently being built meet these requirements. Thanks to the availability of commodity standards that the internet is founded upon, it will be able to implement the system on widely available, scalable network hardware. On the client side, internet technology will ensure platform independence. This is paramount once it keeps down costs of ownership and allows adapting to the rapidly developing marketplace for computer hardware and system software. In table 2, an overview of the technologies and tools used are presented.

Table 2 – Development technologies/tools used

Technology/tools	**Objective**
Oracle version 9, Tools: WebDB	Relational Database
Linux	Operating System and Blackboard implementation
PHP for Oracle	Web programming
Apache	Web server
Adobe Acrobat (PDF)	Document format
Java Servelets	Web programming
C (GTK)	Agents' programming
CGI and PERL	Agents' programming
DICOM Services	Storage, Send and Viewer Plug-in

The priority in terms of implementation was to cover the medical imaging field going from data acquisition and storage to physicians, teachers and student's interfaces. The AIDA system, an Agency for Integration, Archive and Diffusion of

Medical Information [5,19,20], that is at work at several main health care facilities in the north region of Portugal was our choice for heterogeneous data integration. These data is an immensely valuable resource for teaching and diagnostic aid. All these data has a secondary indexing due to protection of the patient's identification. Studies, images and all other medical data are anonymised before they can be used by others rather than the authorised health care professionals. The development of our tutoring system was initiated with the intention to convert this huge repository of information into a knowledge base for e-learning. This knowledge base will form the foundation of a digital network based teaching system in the area of medicine.

3.1 Computational Architecture

The system presents itself with critical features like system's failure or system's breakdowns, so that a scalable three layer computational architecture was conceived (Figure 7):

- **Layer I** - Web applications server's layer where the users interface and the system's software will run;
- **Layer II** - Data Base and application server's layer where the medical data acquisition and handling software will run; and
- **Layer III** - Storage server's layer where the data will be archived (e.g., medical images, clinical data, reports, knowledge base).

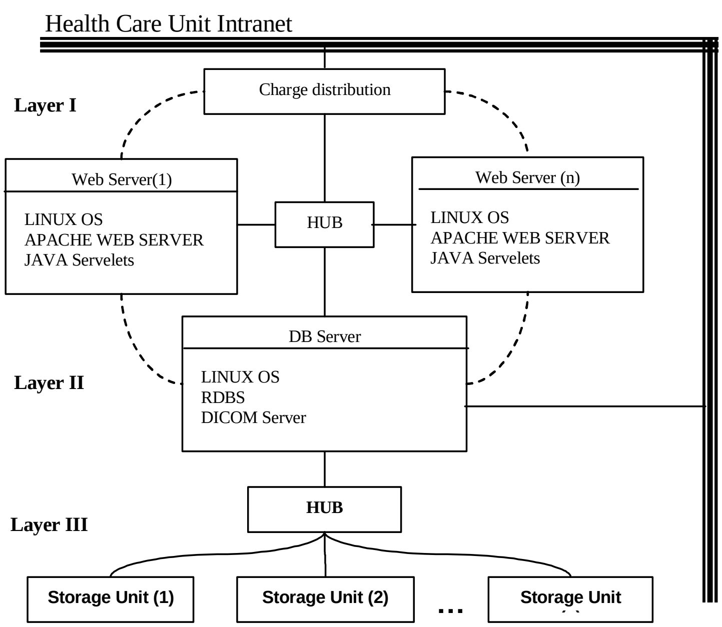

Figure 7 – The three layer computational architecture

3.2 System Building and the Project Team

In this project we had the collaboration of four System Engineers in the programming tasks, a graphic designer for interface designing, four XRay Technicians specialized in the various areas of the medical imaging equipment (Computer Tomography, Digital XRay, Magnetic Resonance and Mamography), three physicians (a Neuroradiologist and two radiologists) and some support from the equipment manufacturers field engineers (*CIT – Centro de Imagiologia da Trindade* (medical imaging company) is a Hitachi Reference Site, in particular to the CT systems).

The system was tested and is being partially used at *Hospital da Ordem da Trindade* (Hospital) and is currently under assessment and in the implementation phase at *ISCS-N Instituto Superior de Ciências de Saúde do Norte* (University).

Despite the system was previously thought for a particular use in the University's medical e-learning field, the sub-systems that implement partial functionalities ended up being desired by the institutions involved. Some are currently in use in some health care Units as well as diagnostic centres.

As the size of the project and its responsibility grew, it meant that we had to do some backup to our supporting of the systems and have currently the development team monitoring and supporting it, receiving feed back and developing new interfaces for new arising situations (Figure 8).

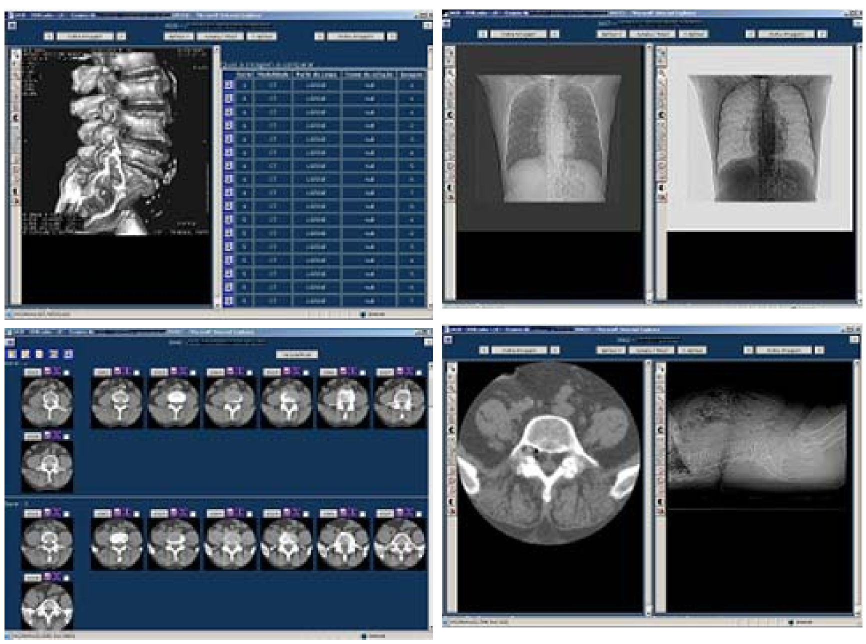

Figure 8 – Interface screen shots

4. Conclusion

The concept that computer systems should be capable of adapting themselves to suit the needs either of individuals or of different classes of users is an apparently attractive, if slightly unusual, one. Early applications of the adaptive system concept have been rather disappointing and problems have proved far harder to deal with than was first expected. Will the dream of having intelligent tutoring agents in the medical arena go the same way?

In this paper we provide an answer to such a question, by presenting a unifying perspective of an adaptive system which facilitates the integration of different sub-systems. Indeed, it uses the more recent advances in problem solving methodologies that use multi-agent systems when applied to the development and evolution of e-learning systems, in this case in the medical arena.

The key success factor of this project was the involvement in the developing team of physicians from the Radiology Department, (Neuroradiologists and Radiologists), Technicians (XRay Technicians) as the image makers, Engineers and Graphic Designer motivated to work and listen to their needs as well as for making the interface with the requesting Physicians, investigators, students and teachers from the University and their teams, who took the trouble of analysing, experimenting and giving the feedback needed to help us implement the necessary changes and interfaces to make things more attractive and functional.

5. About the authors

Victor Alves is Auxiliary Professor at Minho University where he received his PhD in 2002. His research interests include medical image processing, multi-agent systems and computer aided diagnostics. In this project he is responsible for the overall coordination and for agent specification and development.

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